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SOLID WASTES RESEARCH NEEDS

Robert D. Bugher

American Public Works Association
Chicago, Illinois

May 1962

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Solid Wastes Research Needs

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Solid Wastes Research Needs

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— Preface —

The American Public Works Association, through its contacts with prominent educators, consultants, public works directors, public health officials, industrial representatives, and sanitary engineers from all levels of government, has been an active participant for many years in efforts to solve the tremendous refuse disposal problem. The Public Health Service has been particularly interested in the public health aspects of refuse storage, collection, and disposal. Their studies and technical assistance have been augmented for the past several years by a limited number of research grants.

Recognizing the increasing importance of solid waste problems and the growing demand for authoritative information on the subject, the APWA Research Foundation, assisted by the Public Health Service, succeeded in publishing two comprehensive manuals -- REFUSE COLLECTION PRACTICE and MUNICIPAL REFUSE DISPOSAL.

While both of these manuals have been acclaimed as excellent references on modern refuse collection and disposal practices, it was felt that new approaches were urgently needed for coping not only with present problems, but future ones as well. Since the annual outlay for refuse collection and disposal services - over $1.5 billion - is exceeded only by expenditures for schools and roads, and practically all of this money is spent on equipment and operation with pitifully small amounts going into research, the American Public Works Association, at its 1960 annual meeting in New York City, adopted a resolution calling upon the U. S. Department of Health, Education and Welfare to establish a broad program of basic and applied research in the field of municipal solid waste disposal.

Following a number of discussions, a contract was negotiated by the Public Health Service with Robert D. Bugher, Executive Director, APWA, to prepare a report delineating specific research projects in the field of solid wastes storage, collection and disposal methodology.

A progress report on this project was transmitted to the Public Health Service several months ago. Research suggestions that were proposed at that time were subsequently incorporated in the so-called Gross Committee Report on Environmental Health Problems which was submitted to the Surgeon General in November 1961.

The assistance of the following individuals is gratefully acknowledged: Mr. Herbert A. Fritz, (field representative, Public Administration Service, and former city manager of Lexington, Ky., Peoria, Ill., and other cities,) who conducted a survey of recent literature; Messrs. Casimir A. Rogus, Director of Engineering, New York Department of Sanitation, and William A. Xanten, Supt. of Sanitation, Washington, D.C., who reported on current European practices; and Mr. Jean L. Vincenz, Director of Public Works of San Diego County, California, who assisted in conducting a series of meetings designed to solicit ideas for research. Although suggestions were received from many persons, Mr. David J. Vargas, Director of Research for APWA, was largely responsible for assembling the material included in this report. The Foundation also wishes to acknowledge the helpful suggestions received from Mr. Ralph Black, Chief of the Solid Wastes Engineering Unit of the Public Health Service who critically reviewed the completed publication.

It is hoped that this effort will help to stimulate the research that is so greatly needed in this important field of activity.

Samuel S. Baxter, Chairman
Board of Trustees
APWA Research Foundation

May, 1962

I

Summary and Conclusions

The basic requirements for satisfactory disposal of solid wastes were clearly stated by Hering and Greeley* forty years ago as "(1) absence of danger to public health, (2) minimum nuisance to the public, and (3) minimum expense that will effect a sanitary disposal of all refuse materials." Technological developments of recent years clearly indicate that the solid waste production and disposal patterns of the past probably will be significantly modified during the next two decades, even though the basic requirements remain unchanged. Some persons, for example, are convinced that disposable clothing will soon be a reality. Others predict that techniques will one day be developed to utilize the energy value of refuse to heat water in homes or to produce animal foods, drugs and other useful products. The prospects of other significant departures from present patterns of living is further indicated by the trend toward high-rise apartments in suburban areas, and the increased use of mobile homes.

These and other predictions and developments indicate that a comprehensive study of trends and developments in the chemical and manufacturing segments of our economy, plus changes in population movements and living habits would be of tremendous value in making long-range forecasts of the needs for solid wastes facilities in the future. Such forecasts are obviously needed if such facilities are to be designed and financed most efficiently.

The amount of research that needs to be undertaken in the solid waste field is not in any way limited to the projects described in this report. Since existing needs and conditions vary widely among communities, no attempt has been made to give priority to any particular project or group of projects. Obviously, some are more important than others. For example, studies to reduce quantities of wastes, or the development of a method of systems analysis of collection practices would presumably be of widespread interest since all communities, to a greater or lesser extent utilize refuse collection and disposal services. On the other hand, some communities which rely exclusively on landfill disposal, and will continue to be able to do so, would probably have little interest in studies to improve the operation of central incinerators. However, a major breakthrough in on-site disposal techniques might change completely the role of municipal collection and disposal.

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* Hering, Rudolph, and Samuel A. Greeley, Collection and Disposal of Municipal Refuse. McGraw-Hill, New York, 1921, 666 pp.

Although expenditures for solid waste handling are among the highest items in a great majority of municipal budgets, the corresponding expenditures for research in this field are pitifully small, constituting only a fraction of one percent. By comparison, many industries spend up to 5% of their budgets on research and development, and the percentage for the so-called space and electronics industries are, understandably, much higher.

In view of the tremendous opportunities for improvements in the solid waste field, and the urgent need for reductions in capital and operating costs of municipal refuse handling functions, public agencies - including the Federal Government, should follow the example of private industry and invest at least one-half of one percent of the annual refuse collection and disposal bill in research and development. This would finance a $7.5 million research program which would undoubtedly produce many significant advancements in this particular field of activity and result in better service and lower costs to the general public.

Many of the advancements that have been made in the solid wastes field have resulted from the experimental and development efforts of private industry, in spite of the fact that progress has been hampered by the lack of adequately trained personnel. Private industry should, by all means, be encouraged to continue to develop new and improved refuse handling equipment and processes. Public agencies, on the other hand, have definite responsibilities in connection with the development of a healthful environment for community living and should assume their proper role in promoting improvements in this field through a coordinated research effort under the leadership of the U. S. Department of Health, Education and Welfare. The Federal Government has invested millions of dollars in support of research on liquid and gaseous wastes, but its support of research to find better ways and means of handling solid wastes has amounted to an average of only about $70,000 per year during the past three years. Funds for demonstration projects are likewise needed to speed up the acceptance of research findings and overcome the reluctance on the part of local units of government to try out new ideas and/or products which have not been subjected to extensive field tests.

It is recommended that a Conference on Solid Wastes Engineering and Administration be held at an early date. Such a conference should be designed to lay the groundwork for an on-going research program at colleges and universities which would be patterned after federally supported research programs in the highway and water pollution control fields. Interested educators from the leading colleges and universities (particularly those from civil and sanitary engineering schools) should be brought together at such a conference.

Since adequate instructional materials are now available for a college level course in solid wastes engineering, it would be logical to begin to develop an outline for such a course as part of the conference program. Such a course would not only help train competent research investigators but would also provide valuable pre-entry training,

in a much neglected field, for those students who subsequently will assume responsibilities for municipal sanitation operations. It would also provide competent instructors for in-service training programs that are likewise needed in this field in order to disseminate research findings to the men-on-the-job.

To initiate such an on-going program, funds could be made available to colleges and universities to finance the employment of an instructor for such a course who would also devote part of his time to research on projects such as those suggested in this report. Fellowships might also be provided to students who wish to serve as research assistants on solid waste projects while working on post graduate degrees.

This study clearly indicates that a comprehensive research program is definitely needed in the solid wastes field. It suggests many worthy projects and points out that the annual expenditures in this field - using industry standards as a guide - justify the annual investment of at least $7.5 million in research. It also indicates that the Federal Government has already set a precedent of financing research on liquid and gaseous wastes and that it should logically support a broad, well conceived research program in the solid wastes field. Finally, it recommends specific steps to establish an on-going research program which would be of practical value to local officials who are largely responsible for refuse collection and disposal activities.

II

Introduction

The health, comfort and well-being of the American people have been significantly advanced during the past half-century. Much of this progress can be attributed to the industrial revolution which has transformed this Nation into a highly urbanized society.

Technological achievements in virtually every facet of the economy have had a dynamic effect upon the urban pattern of living. Some segments of the population obviously have derived greater benefits from such progress than others. This, of course, has been true from the beginning of time. There is little doubt, however, that our free-enterprise economy, functioning under a democratic system of government, has produced for the American people the highest standard of living in the history of mankind.

Increasing concentrations of people in urban areas, on the other hand, and improved living standards, causing the per capita production of refuse to rise, have accentuated the solid waste disposal problem. Refuse collection becomes increasingly difficult and the number of suitable disposal sites is diminishing rapidly. The relative effects of these wastes on man are growing at an ever increasing rate. "Health officials point out that the success of fly and rodent control programs is dependent upon adequate storage, collection and disposal of community wastes. They have also noted a relationship between the incidence of certain diseases in both humans and animals, and improper refuse disposal practices. Many public nuisances, such as smoke, odors and unsightliness can also be traced to unsanitary refuse collection and disposal operations." * It should likewise be noted that mishandling is costlier than the use of good refuse disposal methods. The economic losses in medical bills; fire and rodent damage; air and water pollution; use of makeshift insect sprays, traps, and poisons; exterminator's fees; and depreciated property values -- can be staggering. Prompt and efficient collection and disposal of refuse are therefore essential to the establishment and maintenance of a healthful environment for community living.

* Municipal Public Works Administration - 5th Edition, International City Manager's Association, Chicago, 1957, 449 pp.

Studies conducted by the American Public Works Association and the Public Health Service show that less than half of the cities and towns in the United States with populations over 2,500 employ approved sanitary methods of disposing of the estimated 90 million tons of refuse they produce each year. This situation is due, in part, to the evolutionary nature of the refuse disposal function and the lack of a universally accepted philosophy for handling such wastes. Local units of government have gradually assumed varying degrees of responsibility for providing satisfactory refuse collection and disposal service. Many actually operate municipal collection systems, some arrange for satisfactory service to be provided by private contractors, while others have done little or nothing to alleviate the individual's burden of disposing of such wastes in a safe, economical and sanitary manner.

Under these circumstances, it is not surprising that there has been a lag in research in this particular field of activity. In undertaking an investigation of solid wastes research needs, it was found convenient to consider separately each of the following phases of the subject: 1) reducing quantities of solid wastes; 2) refuse disposal at the point of origin; 3) refuse storage; 4) refuse collection, and 5) central refuse disposal. Each chapter, which deals with one of the above functions, contains a brief discussion of the problems associated with that function, and some of the shortcomings of present methods of dealing with those problems. The discussion is followed by a series of proposed research projects which, in most cases, were suggested by members of the American Public Works Association. Many of these projects could be subdivided into two or more independent research studies. Detailed proposals, similar to the one appearing in Appendix C, should, of course, be developed for any specific research study which an investigator may wish to undertake. The proposals contained in this report are simply designed to suggest the scope of needed research in the solid wastes field and stimulate imaginative thinking on the part of those interested in conducting research on refuse collection and disposal problems. Since opinions on the relative significance of these problems vary so widely, no attempt has been made to list the projects in the order of their importance.

It should also be noted that the term "research" has been used in its broadest sense in the preparation of this report. Some projects might more appropriately be called investigations, developmental programs, operational and/or administrative studies. However, they all involve a search for new knowledge or new techniques for accomplishing a given objective and, therefore, are considered to be proper subjects for inclusion in this compendium of solid waste research needs.

Work on this study began in the summer of 1961 with a preliminary survey of literature covering the field of refuse collection and disposal. Current literature was reviewed on a continuing basis as the study progressed. Supplementing the results of the literature survey were ideas and suggestions obtained from correspondence and discussions with recognized experts in the field. Included were representatives of industry and of the planning, engineering, and

sanitation departments of federal, state, and local governments. As a result of this approach in obtaining ideas, it was possible to bring into focus the thoughts of those who have had many years of experience as operators, administrators, educators, and consultants in this field.

A series of five APWA-sponsored meetings were held for the purpose of obtaining ideas for solid wastes research. The first meeting, held in conjunction with the Association's 1961 annual meeting, was one of the workshop sessions on public works research needs. Subsequent meetings were held in Washington, D.C., New York City, Chicago, and Los Angeles, during January and February, 1962. Ideas obtained from the discussions at these meetings were recorded, transcribed, and edited for inclusion in this report.

Supplemental information was obtained from APWA representatives in Europe, some of whom attended the Seventh International Public Cleansing Congress held in Goteberg, Sweden, and others who had private contacts with overseas officials.

Persons who attended the solid wastes meeting and contributed ideas and suggestions for inclusion in the report are listed in Appendix A. Appendix B lists those persons who have interest and experience in the solid waste field, and in response to a questionnaire sent out by the APWA Research Foundation, indicated that they would be willing to participate as investigators or consultants for designated research projects.

III

Reducing Quantities of Solid Wastes

The much-publicized population "explosion" and the accompanying concentration of people in metropolitan areas are the main reasons that refuse disposal has become an acute problem. Rapidly expanding communities find that the cost of hauling to distant disposal sites is becoming increasingly expensive. These long hauls decrease the effectiveness of men and collection equipment, and become more time-consuming as the community expands.

In an effort to keep haul distances short and provide acceptable methods of refuse disposal, community officials turn to more sophisticated methods of disposal. Dumps are converted to sanitary landfills, which cost more to operate, but are more satisfactory from the nuisance, public health and safety standpoint. However, fill sites, especially those near large urban areas, are filled rapidly, forcing the community to haul to distant fill sites or to adopt more expensive disposal methods, such as incineration and/or grinding and subsequent discharge to sanitary sewers.

Obviously, the problem could be simplified if the quantity or at least the volume of waste products were reduced by salvaging or waste reclamation. Salvage operations, which were profitable a number of years ago, have largely been abandoned for economic reasons, the nuisances commonly created, and the interference with normal disposal operations. Yet the fact remains that a reduction in the amount of waste that must be handled by municipal or private facilities would result in substantial savings.

New procedures for salvaging wastes are needed to replace antiquated, costly, and otherwise undesirable methods of scavenging, sorting, and hand picking. Because disposal costs are often financed from general funds or lumped with other operating costs, many large producers of waste are not aware of their true costs of refuse disposal. Often, as is the case with liquid wastes, a large share of the total disposal costs are borne by the community. The result is that there is little or no incentive to reduce the quantity of wastes or find new uses for waste materials.

Human nature, too, plays an important part in the refuse disposal problem. Higher standards of living have made people less conscious of the true costs of present packaging practices. Consumers pay more not only for the convenience of individually wrapped items, disposable cans and bottles, etc., but also for the increased cost of disposing of the empty containers.

Littering is another knotty problem that city officials must deal with. Usually remedial measures consist of passing difficult-to-enforce litter laws, utilizing expensive sweeping equipment, and installing more litter baskets. Such measures, while effective to a limited extent, are symptomatic remedies and seldom bring about a permanent solution to the problem. More work needs to be done in developing public education measures and effective laws such as those suggested by Keep America Beautiful and other public service organizations.

Some studies that offer possible methods of reducing the rate of waste production or otherwise relate to this problem are:

A-1 Solid waste inventory and cost allocation study.

A-2 The determination of new uses for existing wastes.

A-3 The improvement of salvaging procedures.

A-4 Study to determine what action could be taken to reduce refuse quantities.

A-5 Long-range forecast of waste production.

RESEARCH PPOJECT A-1

Title: Solid Waste Inventory and cost allocation study.

Purpose: To determine the types, quantities and rate of fly production of solid wastes that are now being handled, and to determine, in the light of true disposal costs, when alternate methods (i.e. salvaging and by-product development) would be feasible.

Explanation: During the last war, the Federal Government instituted measures requiring the salvaging of metals and other materials from refuse in support of the defense effort. An inventory of such materials would obviously be useful in a similar situation. Even under present conditions more solid wastes probably would be used or salvaged if firms and industries knew the quantities and characteristics of the wastes available. Publication of an inventory by the U. S. Dept. of Commerce, a trade organization, or a private agency set up for this purpose, on an annual, quarterly, or other convenient schedule could aid in establishing a clearing house for solid and semi-solid wastes. At the time the inventory is compiled, the true cost of disposing of each type of waste could also be computed on a unit basis. The feasibility of salvaging or by-product development could then be determined more accurately, since recovery costs could be compared with the true disposal cost.

The sanitation aspects of the operation could likewise be observed, the rate of fly production of commonly encountered solid wastes determined, and recommendations for improved handling methods could be formulated.

RESEARCH PROJECT A-2

Title: The determination of new uses for existing wastes.

Purpose: To reduce the quantity and concurrently the cost of disposal of solid wastes and develop by-products of economic value.

Explanation: Although some materials that are now wasted might be used to produce by-products, individual companies often fail to do the necessary developmental work because costs are high, and the possible profits from recovery operations often appear to be limited. Efforts to initiate industry-wide programs to develop uses for certain types of wastes might prove to be very beneficial. Such programs might also be encouraged by effective legislation or refuse service charges in proportion to the true cost of disposal.

Examples of wastes and possible uses that might be explored more thoroughly are: Organic wastes for making animal feed, antibiotics, enzymes, vitamins, bone calcium phosphates, other pharmaceuticals, and plastics. Discarded tires, which may conceivably be used to produce an additive for asphalt pavements, or as a heat source when burned in special furnaces. Paper wastes which might be used in the production of wallboards, acoustical and insulating materials, fuel briquettes, spray mulches, fertilizer and insecticide carriers, and plastics. Grease and oil wastes from gasoline stations, machine shops, and similar places, are troublesome in sewers and in sewage treatment plants, but might be a useful heat source when burned in special furnaces. Another possibility is the recovery and utilization of metals from incinerator residues. Incinerator ash might also be used as a cover material at refuse landfills if simple tests

and standards were developed for determining necessary characteristics (moisture, organic content, etc.) for acceptability. Fly ash might be used as an additive for concrete or insulating materials, a soil stabilizer, or a carrier for fertilizers and insecticides. Oxides of carbon and nitrogen from incinerator stack gases might also be used in the production of fertilizers and other chemicals.

These are only a few of the many possibilities that exist. Presumably, there are in addition some manufacturing processes that might be altered so as to produce wastes that are amenable to reclamation. Research investigations such as those undertaken by the petroleum and by the pulp and paper industries, would undoubtedly bring to light much valuable information on the subject of waste reclamation.

RESEARCH PROJECT A-3

Title: The improvement of salvaging procedures.

Purpose: To reduce the cost, health hazards and nuisances of salvaging and thus make it a more practical method for reducing the amount of waste that must be handled at municipal incinerators and landfills and reclaiming materials of economic value.

Explanation: Existing salvaging operations require costly manual labor, are unsanitary, frequently creating serious hazards to health, and often interfere with normal disposal operations. In many cases salvaging is not practical because little or no profit can be derived from the operation. Approaches for improving the situation are:

a. The development of improved mechanized equipment - reciprocating screens, magnetic separators, blowers and sorting belts - for separating paper, textiles, etc., and recovering metals from mixed refuse and from incinerator ash. Improvements are also needed to protect workers from breathing dust from the operations. European systems for this work are generally more advanced than American systems.

b. A study of the feasibility of using neighborhood collection stations or mobile units (similar to bookmobiles) that would buy or refund deposits on waste paper (magazines, newspapers, cartons, etc.), cans, bottles, rags and other salvageable materials. These items could then be sold or returned to cooperating industries or agencies. Such a system could perhaps be operated by a municipal refuse

collection agency, a private firm or a charitable or service organization (e.g. Boy Scouts, Salvation Army).

c. The investigation of swine feeding operations and the development of health standards and economic yardstic for using garbage from commercial and institutional sources as feed for animals.

RESEARCH PROJECT A-4

Title: Study to determine what action could be taken to reduce refuse quantities.

Purpose: To determine methods of distribution less contributory to litter and develop mutual understanding and cooperation between the major waste producing industries and waste disposal agencies for the purpose of alleviating some of the problems commonly associated with waste disposal operations.

Explanation: The packaging industry has made tremendous contributions to the safe and healthful distribution of a wide variety of materials and food products, but little consideration has been given to its effect on the waste disposal function. Packaging officials report that within the next five years, 60% of all soft drinks will be sold in no-return bottles*. While such bottles are a convenience to consumers and to retailers alike, and a source of profit to the industry, their use increases the work and consequently the cost of refuse disposal and litter control. Studies are needed to consider and develop alternate solutions to the problem. One alternative, for example, might be to change bottle shapes so that they can be cleaned more easily. Simple tumbler-shaped containers with spillproof polyethylene tops for milk, beer, and other beverages might be more useful and easier to clean and reuse. Making the containers returnable for a deposit refund could con-

*"60% of Soft Drinks In 1-ways by '67", Food and Drug Packaging, 1 February 1962

ceivably reduce the number of discarded cans and bottles that now litter streets and highways.

Double and triple wrapping might be eliminated through the use of newly developed packaging materials. Recently it has been announced that a process has been developed for making paper impermeable to odors, liquids, fats and gases.* The use of impermeable paper and/or plastics for containers for juices, liquors, milk, edible oils, and other products might likewise be very advantageous from a waste handling point of view.

Efforts should also be made to encourage the packaging industry to develop and use containers which can be easily reprocessed for some beneficial use.

*"Treat Paperboard with New Methods" - Food and Drug Packaging, 18 January 1962.

RESEARCH PROJECT A-5

Title: Long-range forecasting of waste production.

Purpose: To establish uniform methods of analysis of refuse and determine methods for predicting possible changes in solid waste characteristics, and the resulting effects on existing collection and disposal systems.

Explanation: Significant changes in refuse characteristics over the years have greatly affected collection and disposal practices. The ash content has been significantly reduced by the use of gas, oil and electricity in place of wood and coal for heating and cooking. The amount of garbage is much less in neighborhoods where garbage grinders have been installed. On the other hand, as lot sizes increase, there will be more yard rubbish. Paper, wood, plastics, metal foils, and related products are being used in increasing quantities. Some authorities are even predicting the use of disposable clothing in the not too distant future. Air pollution regulations have discouraged on-site burning of combustibles. Yet, significant improvements in on-site disposal methods, and the growing popularity of high-rise apartment dwellings might completely change the collection and disposal picture long before existing waste disposal facilities have been amortized.

Research is needed to determine the relative importance of the many variables (technological developments, population movements, living habits, etc.) that affect the content and quantity of refuse, and to develop reliable barometers for predicting

collection and disposal facility needs.

Research to determine the physical and chemical characteristics of refuse was initiated by the APWA several years ago and is now under way at Purdue University. Supplemental studies, however, are needed to develop refinements in the "Tentative Methods of Analysis of Refuse and Compost" as published in the Association book on Municipal Refuse Disposal. A continuing waste testing program should also be undertaken to obtain comparative data on the quality and quantity of refuse produced in representative cities in different parts of the country. A mobile testing laboratory traveling from one city to another could, perhaps, be utilized in conducting such a program. Progressive changes and trends could thus be determined which would serve as a continuous guide in planning refuse collection operations and designing refuse disposal facilities.

IV

Refuse Disposal at the Point of Origin

Although substantial progress has been made in the field of on-site disposal during the last quarter century, it is still a source of real concern to health authorities and sanitary engineers. The hazards and nuisances caused by backyard burning are well known, and, as a result of increasing air pollution problems, the practice is now outlawed in some cities. Modern garbage grinders and incinerators, if properly operated, can reduce domestic and commercial solid wastes in a less objectionable manner, but certain problems are associated with these methods.

The advantages of reducing refuse to a stable form at its point of origin are significant. Health and aesthetic problems (e.g. insects, rodents, odors, fire hazards, blowing papers, unsightly containers, etc.) associated with on-site storage are eliminated, general sanitary conditions are materially improved, and the cost of municipal collection and disposal is significantly reduced.

Unfortunately, there are certain disadvantages associated with on-site grinding and incineration. Some of the objections to present day garbage grinders are:

1) Relatively high costs, which range from $75 to $200 or more for an installed grinder, plus approximately $6 a year for maintenance and operation.

2) Increased load on sewage treatment facilities or on the receiving stream if no treatment is available. It is estimated that approximately 50% more digester capacity would be needed if all of the garbage in a community were ground and discharged to the sewers. When grinders are used with septic tank systems, larger tanks must be installed or more frequent pumping is necessary.

3) Increased water consumption unless provisions have been made for recirculating the flush water.

4) Not all wastes can be handled by grinding. Refuse collection service is still required for cans, bottles, bones and papers, which may contain putrescible wastes.

Incinerators are able to dispose of greater quantities of domestic solid wastes, but they too have shortcomings. For example:

1) High costs, ranging from $100 to over $200 for the installation of a home incinerator, plus approximately $30 to $40 a year for operation and maintenance. (These figures are for indoor auxiliary fuel type incinerators.)

2) Apartment-house, institutional, and some home incinerators require a skilled operator for satisfactory operation. Improperly operated units are a potential fire hazard, produce odors, and contribute to air pollution problems.

3) Not all wastes can be incinerated. Refuse collection service is still required for cans, bottles and some bulky wastes. The ashes produced have to be removed periodically, and are apt to produce dust and dirt near the unit.

In spite of their shortcomings, home grinders and incinerators, as well as the larger units designed for apartment and office buildings and institutions, are both convenient and useful. They also help to reduce the load on the municipal collection and disposal agency.

Some investigations that offer possible methods of making on-site reduction more effective are:

B-1 Improvement of existing home and institutional garbage grinders.

B-2 Improvement of existing on-site refuse incinerators.

B-3 Development of an on-site refuse composting unit.

B-4 Determine feasibility of compressing, shredding and packaging refuse on premises.

RESEARCH PROJECT B-1

Title: Improvement of existing home and institutional garbage grinders.

Purpose: To overcome some of the disadvantages of present-day grinders in order to make them a more versatile method for disposing of municipal refuse.

Explanation: Garbage grinders eliminate the need for storing putrescible refuse and simplify refuse collection service work. The grinder requires less operating skill than an incinerator, and causes no air pollution difficulties. Generally, the units are less expensive to install and operate than an auxiliary fuel indoor-type of incinerator, but they are not as versatile. Grinders are particularly effective in handling hotel and restaurant wastes, which usually have a high moisture content. The following studies have been proposed to overcome certain problems associated with the use of garbage grinders:

(1) Determine effectiveness of biological and chemical type cleaners for unclogging sewers. At the same time, it could be determined if grease traps are actually needed in many places where they are required by existing plumbing codes.

(2) Evaluate design criteria for critical conditions, including a study of pipe materials, slopes and sizes; required flushing techniques when solid wastes are discharged into sewer systems.

(3) Investigate the feasibility of using flush tanks in

connection with garbage grinders that would not require large volumes of running water.

(4) Investigate possibilities of modifying equipment and operations at sewage disposal plants to simplify the handling of combined liquid and solid wastes. Examples might be changes in the design and/or operation of pumps and settling basins.

RESEARCH PROJECT B-2

Title: Improvement of existing on-site refuse incinerators.

Purpose: To explore possibility of utilizing heat value of refuse and overcome the disadvantages of air pollution, high cost, production of offensive odors, and other objectionable characteristics often associated with on-site incinerators.

Explanation: Incinerators, if properly operated and maintained, can provide a 75-95% reduction in refuse volume, and eliminate the need for storing putrescible and other combustible refuse, particularly waste paper, which often becomes a fire hazard in homes, apartment buildings, and offices. Another advantage of incineration is the possibility of using the excess heat for auxiliary heaters for water and for space heating in homes and in larger buildings. The following projects have been proposed to overcome certain problems associated with the use of on-site incinerators:

1) Studies to determine the optimum grate size, combustion chamber shape and volume, proper feeding rate and the best auxiliary equipment for reducing the ash and odor content of effluent gases in order to comply with requirements established by air pollution control agencies. Some work on improving home incinerators has been done by the American Gas Association and several manufacturers, but more work is needed to improve the efficiency of these units and to make them as maintenance-free as possible.

Improvements are also needed in the larger units, such as those used in apartment buildings, offices and institutions. Automatic controls for feeding and firing, and for controlling combustion temperatures and stack emissions would offer real advantages.

2) Studies to determine the economic feasibility of granting tax concessions to incinerator owners in proportion to the saving realized by tax supported refuse collection agencies. Although the many improvements needed in on-site incinerators would undoubtedly increase the purchase cost of such incinerators, it has been suggested that tax concessions to persons installing such units would promote increased usage of home incinerators and affect overall economies in waste disposal costs.

3) Studies might likewise be undertaken to explore the possibility of utilizing heat from on-site incinerators to supplement space and hot water heating systems. It has been reported that the refuse generated by a person in one day (approximately 2 pounds) has about the same heating value as 5 cubic feet of gas. Research is needed to discover practical methods of utilizing this energy, which is now wasted.

RESEARCH PROJECT B-3

Title: Development of an on-site refuse composting unit.

Purpose: To dispose of domestic refuse in a convenient, nuisance-free manner, and produce a compost that could be stored and used as needed.

Explanation: An on-site refuse composting unit would consist of a small loading bin, a grinder, and a small holding unit. Home refuse, except cans, bottles and other ungrindable objects would be fed into the unit, which would grind, digest and store the resulting compost for use as needed.

Many families could easily use the compost in their own yards; however, any excess could be collected and used as fill material in new subdivisions or in marshy areas. The compost would be stable and free from the objectionable characteristics of raw refuse that must be frequently collected.

RESEARCH PROJECT B-4

Title: Determine feasibility of compressing, shredding and packaging refuse on premises.

Purpose: To reduce the amount of space necessary for storing refuse and/or to permit less frequent collection (while at the same time decreasing the hazards of fly breeding), and to simplify collection and disposal operations.

Explanation: Most refuse could easily be crushed and compacted to half of its original volume or even less, on the premises, if a satisfactory crushing mechanism were commercially available. The refuse could be dewatered by presses, compacted, baled, and stored in moisture-proof sacks or plastic bags. A system such as this might be particularly useful for large producers of solid wastes including large apartment and office buildings. Collection could be less frequent, would not require heavy, noisy and expensive compaction vehicles, and transfer and landfill operations could be greatly simplified.

V

Refuse Storage

The storage of refuse for subsequent collection and disposal has long been a problem, yet with a few exceptions found in the storage of commercial and industrial refuse, there has been little change in practices. In spite of the fact that its importance is so apparent, probably the most significant change in the history of refuse storage has been the requirement of standard covered containers in some communities.

Although it would be most desirable from the standpoint of health and convenience to eliminate on-site storage altogether, this is not possible at the present time. Even with the use of modern devices such as grinders and incinerators, cans, bottles, and other bulky or non-combustible items must be stored. Moreover, where satisfactory collection and disposal services can be provided at a lower cost than on-site disposal, the problems associated with maintaining satisfactory refuse storage will continue to require considerable effort.

Even though refuse storage is generally an indispensible function, and, as such, continues to be a source of problems for public health inspectors, it is seldom given adequate consideration by builders and designers. A number of sanitation officials have pointed out that homes and buildings, especially if they are still in the planning stage, could be constructed so as to minimize refuse handling within the building and to minimize the work of the collection agency. The temporary storage of garbage and other refuse is a source of continuing problems for health department officials, particularly at restaurants, hotels and other eating places. Seldom are proper provisions made in order that garbage containers can be cleaned in a reasonably sanitary manner. The use of disinfecting and/or odor masking agents in connection with refuse storage problems are also in need of further study.

A comparative evaluation of waste handling methods in high-density, multiple-family districts and low-density suburban areas would be most enlightening. New trends to design and develop mobile-home parking structures in downtown areas likewise offer interesting opportunities to incorporate new waste handling concepts in such facilities.

Another problem - that of littering - is associated with inadequate and poor storage practices and should also be given careful consideration. Potential studies that offer possible methods of overcoming some of the problems connected with on-site storage of refuse are:

C-1 An evaluation of refuse containers to determine types most suitable for storing various kinds of refuse under specified conditions.

C-2 An evaluation of in-building collection and storage systems to determine which are most suitable for various kinds of wastes.

C-3 A study to determine the optimum size and best location for storage containers.

C-4 The development of standards for architects and builders for providing acceptable and convenient refuse storage facilities for homes, multi-story buildings, commercial establishments, and institutions.

C-5 A study to determine more effective methods of dealing with the litter problem.

RESEARCH PROJECT C-1

Title: An evaluation of refuse containers to determine types most suitable for storing various kinds of refuse under specific conditions.

Purpose: To overcome the shortcomings of existing refuse containers, and to develop types of containers more suitable and acceptable from a public health standpoint for use in different climates and for different kinds of refuse. Design must provide for efficiency in handling as well as economy in construction and maintenance.

Explanation: The cylindrical metal cans now used to store refuse by most homeowners and many businesses and institutions have a number of disadvantages. Metal cans become unsightly, bend easily, rust, fall apart, are relatively heavy, noisy, and difficult to keep clean; often lose their covers, and are often blown away on a windy day. Some of these difficulties can be overcome with a little planning and effort on the part of the owner, but such effort is usually lacking and the trouble persists unless the collection agency is willing to furnish the container and keep it clean. Such additional service, however, adds to the cost and complexity of refuse collection operations.

Studies could be undertaken to determine the economic feasibility and sanitation benefits of using disposable containers in refuse collection operations. Pliable containers, for example, suspended from special racks or enclosed in rigid containers may help to overcome the disadvantages of noises during handling, high tare weight, rapid corrosion, and poor sanitation. They could be made

of disposable materials such as plastic or moisture-resistant papers, reusable materials such as nylon, reinforced plastic, or other synthetic materials that would be airtight, waterproof, and easy to clean. Special attention should be given to any problems that might develop from using these materials in wet or freezing climates. It has been observed that rigid plastic containers, while somewhat better looking and not as heavy as metal containers, provide little protection from rats and other animals.

Several companies have developed various sizes and shapes of bin-type containers which are used extensively in connection with housing projects and commercial and industrial operations. Such units have proved to be most effective, but further research is needed to develop efficient methods of cleaning the interiors of such containers and controlling odors and other problems associated with their use.

RESEARCH PROJECT C-2

Title: An evaluation of in-building collection and storage systems to determine which are most suitable for various kinds of wastes.

Purpose: To determine feasibility and sanitation benefits of using chutes and moving belts and develop improved, sanitary and convenient methods for conveying wastes from offices and apartments to central storage or disposal areas.

Explanation: Storage systems must be designed to meet sanitary standards to prevent creation of health nuisances during periods of storage and to permit necessary cleaning and sterilization. Refuse chutes that have been installed in many multi-storied buildings often produce odors, permit breeding of insects, and may be a fire hazard. While chutes can be constructed of fireproof materials and designed to minimize clogging and the accumulation of dirt, no specific criteria for their use has been established. The feasibility of using chutes, pneumatic tubes, or conveyors in conjunction with containers of either the disposable or standard rigid type should definitely be explored.

Another possibility would be to improve the design of refuse chutes so as to make them easier to clean. This could be done by changing the shape, providing for better accessibility, using lining materials that are more easily cleaned, and developing special sprays, gases, or devices for preventing the accumulation of filth and odors.

RESEARCH PROJECT C-3

Title: A study to determine the optimum size and best location for storage containers.

Purpose: To investigate all of the variables that determine what storage requirements are and how these requirements can be met.

Explanation: Most communities have regulations designating how and where refuse must be stored and where it must be placed on collection day; however, there are considerable variations in the effectiveness of these regulations from a health, fire prevention and asthetic point of view.

In order to improve and obtain a greater degree of compliance with such regulations, more must be known concerning the waste handling practices and habits of householders and employees of business establishments. A methods analysis approach to the problem could conceivably lead to the establishment of improved waste storage standards which would not only be more effective but more convenient to the general public.

RESEARCH PROJECT C-4

Title: The development of standards for architects and builders for providing acceptable and convenient refuse storage facilities for homes, multi-story buildings, commercial establishments, and institutions.

Purpose: To acquaint architects and builders with modern refuse storage and collection practices, and to encourage development of designs that will facilitate the provision of suitable facilities in new buildings and homes.

Explanation: Since many architects and builders are not aware of present equipment that can be used for more convenient refuse handling, little attention has been given to the possibilities for improvements in refuse handling in homes and in large buildings. Likewise, inadequate attention has been given to facilitating the work of the refuse collection agency. Therefore, consideration should be given to the preparation of a handbook for architects and builders which would cover design requirements for:

Sanitary and efficient refuse handling systems for use in multiple-story buildings; proper size and location of refuse storage areas and service drives to accommodate bulk containers and collection vehicles; the installation of garbage grinders, and appurtenant plumbing systems and the installation of incinerators in homes and larger buildings; provisions for efficiently cleaning, venting, storing and removing the ashes.

RESEARCH PROJECT C-5

Title: A study to determine more effective methods of dealing with the litter problem.

Purpose: To reduce urban littering caused by present living habits and poor refuse storage practices and establish street cleaning frequency standards.

Explanation: Littering has reached such a stage, especially in the larger cities and metropolitan areas, that a complete evaluation of present litter control practices should be made and more effective methods developed in order to reduce the high costs of sanitary inspection and street cleaning.

Although the amount of littering in a given neighborhood varies with the economic status of the residents, available refuse storage capacity, frequency of collection, climate, season, and other factors, the problem still defies solution. Many citizens subconsciously violate litter control laws, which raises an important question of - how much inspection and enforcement is warranted? Many observers have pointed out that European cities are usually much cleaner than their American counterparts. The reasons for this difference need to be investigated. If differences in attitudes and living habits account for the greater cleanliness in some cities, then these differences should be investigated.

As an added convenience to the public, consideration should also be given to the use of public storage facilities for depositing bundles of securely wrapped refuse. Convenient

refuse receptacles should likewise be designed so that they can be permanently installed in all new autos, trucks, and busses. Service station attendants could then empty these receptacles as part of their regular service, or the maintenance of such receptacles might be enforced by ordinance and/or periodic inspection by licensing officials.

More effective education measures could also be developed to discourage public carelessness and thoughtlessness. Such measures might be presented in the form of classroom lectures or radio and television announcements. Specific information revealed by authoritative studies of actual costs, trends, and health and safety problems caused by littering or poor refuse storage practices would be particularly helpful in obtaining better public cooperation.

Research should also be initiated to develop street cleaning standards for different types and classes of streets. This would necessitate the establishment of systematic procedures for periodically measuring the cleanliness of streets in differently zoned areas of the city and establishment of street cleaning frequency schedules based on the results of such studies. The season, type of street, effectiveness of street sweeping and/or flushing operations and similar factors should obviously be considered in connection with the establishment of such standards.

VI

Refuse Collection

Increasing cost of providing service is probably the most critical of all the problems related to refuse collection. Because so much manual labor is required, collection costs are 3 to 6 times greater than disposal costs for most communities. As communities continue to grow, increased hauling distance and travel time between collection areas and disposal sites will push costs even higher.

In spite of the high cost of collecting refuse, it is expected that demands for more house-to-house collection service will continue until less costly and better on-site disposal systems are available. The same is true of industrial and commercial collection service which is often complicated by traffic congestion, limited storage space, and other special problems in addition to the usual noise, odors, health and safety hazards, and other nuisances associated with standard vehicular collection systems.

Because open refuse trucks do not confine odors, insects, scattered paper, etc., and do not hold as much refuse, most collection agencies have turned to closed compaction vehicles. Such vehicles, however, have certain shortcomings. They are noisy, heavier, and more costly to purchase, maintain and operate. Fully loaded trucks often exceed the design load limit for residential streets.

Manufacturers have introduced the step-in-cab, right-hand drive and various types of new collection vehicles in recent years. These efforts to provide more efficient equipment should be encouraged.

Other problems that have confronted refuse collection officials are pick-up and route scheduling to minimize hauling time and traffic congestion, optimum utilization of manpower, preventative maintenance programming for vehicles and equipment, choice of the most efficient type and size of vehicle, selection of the best location for transfer stations, and the effects of climate, topography, street layout, population density, and disposal method on equipment requirements.

An intensive research program is needed to improve existing methods and to investigate new techniques for more satisfactorily coping with the billion-dollar refuse collection problem. The determination of rational design and location standards for refuse transfer stations would be of benefit to cities where transportation problems are becoming increasingly significant. Obviously, many situations deserve specific economic analysis and special design study, but rational yardsticks should be further developed. Some studies that offer possible methods of improving refuse collection service are:

D-1 Improvement of collection vehicles.

D-2 Development of new types of refuse collection vehicles.

D-3 Systems analysis of refuse collection operations.

D-4 Development of work standards for refuse collection personnel.

D-5 Study of underground refuse collection systems

D-6 Improvement of refuse handling operations at transfer stations.

RESEARCH PROJECT D-1

Title: Improvement of refuse collection vehicles.

Purpose: To increase overall efficiency of refuse collection vehicles and decrease operation and maintenance costs.

Explanation: Among the objectionable characteristics of many refuse collection vehicles are excessive noise, production of objectionable odors, excessive weight, and necessity for manual loading. Recent improvements such as step-in cabs, right-hand drive controls, hydraulic compaction and loading mechanisms, etc., have helped to increase efficiency, but there are other possible improvements that should be tested and developed. These include simplified mechanical or vacuum-type loading devices, lightweight interchangeable truck bodies, and lightweight engines that are specially designed for stop-and-go driving.

Studies are needed to determine the feasibility of using flexible vacuum tubes to convey refuse from the container to the collection vehicle without having to lift or move the can. Such a device might also be designed so that it can be used to pick up street and yard litter.

Lightweight detachable bodies need to be developed to reduce chassis and street wear, and to simplify transfer operations. The feasibility of using containers that could be detached from the truck chassis and compaction mechanism, and transported via trailer, railcar, or helicopter to the disposal site should also be explored. Materials that have

been suggested for constructing such containers or other types of truck bodies include aluminum, magnesium, fiberglas, and/or plastic. Materials for this use must be strong, lightweight, corrosion resistant, and easy to clean.

Also needed are compaction and dumping mechanisms that operate more rapidly with less noise and less maintenance. Improved engines and transmissions are needed to more economically move heavy compaction trucks at slow speeds with frequent starts and stops. Specially designed diesels, similar to those used in some European vehicles might also prove to be more satisfactory than conventional gasoline engines which are used to power refuse collection vehicles.

RESEARCH PROJECT D-2

Title: Development of new types of refuse collection vehicles.

Purpose: To explore the possibility of grinding, baling or incinerating refuse as it is collected.

Explanation: While the development of existing types of compaction units marks a substantial improvement over open trucks, they only transport refuse and do not actually aid in its disposal. Mobile disposal units might be developed that would be less costly and easier to operate and maintain than individual units located in each home or building. Haul costs would also be greatly reduced because fewer trips would be necessary.

Mobile grinders might be developed for handling mixed or separate refuse and street litter and discharge such wastes into trucks or trunk sewers.

Mobile incinerators could possibly be developed to more economically dispose of combustible refuse and street litter. As with any incinerator, exhaust gases might be used to heat and dry incoming refuse; ashes could be hauled to fill sites or transfer stations, or they could be sluiced into the sewers in the same manner as ground food wastes. Auxiliary fuel could be used for operating afterburners or for drying wet refuse.

Mobile baling units might be developed that could be operated much the same as hay balers used on farms. One unit might be designed to bale and wrap refuse, while a second unit could haul the bales to a transfer station or disposal site.

The transfer of refuse and its placement in a sanitary landfill could thus be greatly simplified. A similar system might be set up, using a high pressure extruding device in place of a baler. It was suggested, for example, that refuse could be extruded into "logs" that could be either burned or put into landfills.

RESEARCH PROJECT D-3

Title: Systems analysis of refuse collection operations.

Purpose: To determine optimum design of collection systems, considering the following variables: 1) location of garaging facilities, 2) location of disposal facilities, 3) frequency of collection, 4) location of transfer sites, 5) number of vehicles, 6) size of vehicle, 7) number of men per collection area, 8) separate collection of two or more classes of refuse, 9) location of storage sites, 10) vehicle route patterns.

Explanation: A detailed proposal for this study has been prepared by Walter R. Lynn, Associate Professor at Cornell University, and is included as Appendix C of this report. Such a project might lead to the development of minimum standards for refuse collection service which could have a significant influence upon the level of service provided by refuse collection agencies and/or contractors in cities and towns across the nation.

A research study to develop a uniform system of reporting refuse handling statistics should also be undertaken at an early date. The use of data processing equipment to analyze refuse collection and disposal statistics supplied by cities willing to conform to standard reporting procedures, could be of tremendous value in improving the management of refuse collection and disposal activities.

RESEARCH PROJECT D-4

Title: Development of work standards for refuse collection personnel.

Purpose: To increase the efficiency of refuse collection operations, and reduce accidents.

Explanation: Work standards, based on carefully conducted time and motion studies, would aid collection agencies in setting up work schedules and collection routes. Variables that need to be investigated are: climate (including temperature and humidity), topography, street layout, population density, collection frequency, type of refuse, vehicle design, and the effects of rotating drivers and collectors.

Special attention should be given to the establishment of safe operating procedures to protect employees from the hazards associated with refuse collection and disposal operations. It is significant to point out in this connection that refuse collection employees have a higher accident rate than any other group of municipal employees. Research studies should therefore be undertaken to identify hazardous operating conditions and develop protective devices and procedures to minimize the time employees are exposed to such dangers.

RESEARCH PROJECT D-5

Title: Study of underground refuse collection systems.

Purpose: To develop a refuse collection system meeting optimum health and sanitation requirements, avoiding air pollution control problems, and free of the noise, traffic congestion, manual labor requirements, and other objections to vehicular collection systems.

Explanation: Pneumatic systems should be investigated that could be used to convey refuse from the point of origin to a substation or central disposal site. Such a system may be particularly suitable for a new subdivision, but they have also been envisioned for serving industries and commercial establishments. In addition to the Gandillon vacuum system which has been used in France for several decades*, two new systems have been proposed: one employing rigid containers for transporting compacted refuse through a vacuum tube, and another that would not require any container. The container system might operate intermittently, allowing for the collection of full containers and the return of empties during specified hours, while the containerless system might be operated under a continuous vacuum.

House-to-house collection would be required only for large items that would not fit into the pneumatic system. Flushing water, which is essential in water-carriage systems, would not be needed. No fly ash or odors would be released to the surrounding atmosphere. Some reduction, such as baling, compressing, grinding, or incineration might possibly be accomplished at the substation, or the refuse could be

transported during off-hours by rail, truck, barge, or helicopter to a distant disposal site. Substations might also be located along large trunk sewers and equipped with grinders for direct disposal to the sewer system. The non-combustibles could be salvaged, sending only the shredded combustible materials into the sewers.

In areas where construction of pneumatic lines to a substation might be delayed, refuse collection trucks designed to receive refuse through the pneumatic system leading from the building to the curb could be utilized.

*Szniolis, A., "Gandillion's complete Municipal Sewerage System," Sewage and Industrial Wastes, June, 1962, pp. 752-59.

RESEARCH PROJECT D-6

Title: Improvement of refuse handling operations at transfer stations.

Purpose: To achieve reduction of collection costs, particularly costs of haul following last pickup point.

Explanation: As haul distances to sanitary landfill and to other disposal sites become greater and as traffic on major transport routes becomes increasingly heavy, substantial amounts of time are wasted in the round trip between the collection area and the point of disposal. Public works officials have found that there is a point at which it becomes desirable to utilize a transfer station to which the regular collection vehicles can drive, and at which point they can discharge their loads, returning for their additional collections.

By means of the transfer stations, a number of smaller loads can be deposited in trucks of considerably larger size for transport to distant disposal sites. Transfer stations are also used when refuse is to be transported by rail or barge.

Although many cities have realized substantial savings through the use of refuse transfer stations, it seems certain that the operation can be improved with further study. In addition to obvious features that would increase efficiency such as proper capacity of the storage bins, methods of cleaning, methods of operating the various parts of the station, etc., studies might reveal the desirability of providing a sorting belt where many of the salvageable materials could be removed at this point at possibly a minimum of cost in relation to salvaging at any other point in the collection and disposal operation.

Some studies have been made by the Public Health Service of the desirability of baling the refuse after compressing to approximately 100 pounds per square inch. Such bales could then be loaded onto a low-boy designed to transport the maximum weight on the highways to the point of dis-

posal. It might be found desirable to enclose the bales in neoprene or some such material. It has been suggested that for cities on the seaboard, an inexpensive method of refuse disposal would be to load the bales contained in the neoprene cover onto a barge from the transfer station and carry them out to sea. Inasmuch as the weight of each bale would probably be in the neighborhood of 1100 pounds, the bales should sink without the present difficulties that are experienced in having refuse washed back to the shore.

The bales, without the neoprene, could be stacked in areas of the sanitary fill with a minimum of earth-moving, paper blowing and odors, and a savings of costs of compaction, etc. It is also conceived that because of the improved sanitary condition of such bales, there should be little objection to placing them in smaller areas requiring filling and located much closer to homes and places of habitation.

VII

Central Refuse Disposal

Although there have been many improvements in refuse disposal techniques during recent years, those who are familiar with these improvements are among the first to agree that many serious problems remain to be solved. Of the three acceptable disposal methods, only two - sanitary landfilling and incineration - are used extensively by communities in this country. The third method, composting, is widely used in other parts of the world, particularly in Europe and in Asia where there is a considerable demand for soil conditioners and the nutrients that are found in compost.

Since chemical fertilizers are relatively cheap and plentiful in the United States, less emphasis has been placed on the agricultural values of refuse, and more on the simpler methods of volume reduction and stabilization. While sanitary landfilling is the least expensive of acceptable disposal methods, much more land is required than with central incineration, and a long period of time is generally required to achieve stabilization. A sufficient quantity of adequate cover material may be difficult to find at a fill site, and in some locations there is danger that water supplies might be polluted by runoff water that has percolated through layers of partially decomposed refuse. In addition, landfill operations may be difficult in bad weather, when rains turn unpaved access roads to mud, freezing temperatures slow earth moving operations, and high winds blow dust and papers.

While the low cost of operation is probably the greatest single reason why landfills are used so extensively, another reason is that swamps, canyons, gravel pits, and other "wastelands" can be reclaimed. However, the use of such completed sites for housing and industrial buildings too often must be limited or restricted because of unstable conditions within the fill. Gases are sometimes produced which may have objectionable odors, and may even be a serious fire or health hazard. Unpredictable, uncontrolled and frequently unevened settlement experienced at some sites, complicates the design of structures placed on the fill, and may result in severe damage. Settlement may also damage pavements and utility conduits placed on or in a completed fill. Acid or corrosive soils have been another troublesome factor at some landfills.

As existing landfill sites are used up, the ever-increasing costs for land and hauling often force larger communities to turn to incineration as a method of refuse disposal. The high volume reduction achieved with this method (up to 95%, as opposed to a possible 50% in landfills) makes it possible to conduct disposal operations on a much smaller plot of land, thereby saving on land and hauling costs. Moreover, incinerators are not affected by weather conditions.

Often some income can be derived from the recovery of heat energy and salvageable metals.

On the other hand, capital costs, as well as operation and maintenance costs, are relatively high, and ashes, along with other furnace residue, must still be hauled to a disposal site. In some areas air pollution is a serious problem and control requirements adopted by health authorities actually preclude the operation of refuse incinerators. Other common objections are unsightly appearance, noise, odors, and traffic congestion caused by the movement of collection vehicles in the area.

While it is possible that many of the objections to both landfilling and incineration may be overcome, it is obvious that the intensification of efforts to improve the effectiveness of other methods of disposal would be desirable. Composting, which is an acceptable method of disposal in many overseas communities, may in some instances be utilized to advantage in this country. Central grinding, distillation, wet incineration, and fluidized bed oxidation, are other methods which also need further investigation.

Several studies that offer possible methods for improving refuse disposal methods are listed below. A limited amount of research has already been undertaken on some of the proposed areas of study but further work is definitely needed.

Landfill

E-1 Study of factors affecting settlement, fly emergence, and decomposition of refuse in sanitary landfills.

E-2 Effect of sanitary landfill operations on water quality.

E-3 Development of effective methods of increasing the capacity of sanitary landfills.

E-4 Development of effective methods of preventing surface erosion of completed fills.

E-5 Establishment of standards for development of sanitary landfill sites for pre-determined uses.

Central Incineration

E-6 Development of automatic controls and monitoring instruments for operating all components of municipal refuse incinerators more efficiently.

E-7 Improvement of the existing components of refuse incinerators to reduce overall costs and reduce stack emissions.

E-8 Development of techniques and devices for economically separating non-combustible and combustible refuse at central incineration plants.

Composting

E-9 Complete study of the potential market value and relative merits of refuse composting.

E-10 Development of methods of accelerating the composting process and of improving the usefulness and quality of the end-product.

General

E-11 Development of package refuse disposal units - grinders, shredders, incinerators, and balers - for use in small communities or at neighborhood transfer stations.

E-12 Development of improved methods of handling demolition refuse and other bulky wastes.

E-13 Investigation of wet incineration, accelerated chemical and biological decomposition, and other possible methods of refuse reduction.

RESEARCH PROJECT E-1

Title: Study of factors affecting settlement, fly emergence, and decomposition of refuse in sanitary landfills.

Purpose: To determine methods for controlling and predicting settlement, increasing the rate of decomposition, and controlling emergence of flies from sanitary landfills.

Explanation: It has long been known that refuse decomposes rapidly in some fills, and may take much longer in others. The chemical and biochemical processes involved should be studied so that they can be accelerated and controlled. Settlement and gas production may create problems long after a fill has been completed and put to use as a recreational area, parking lot, or building site. Better stabilization might be achieved in a number of ways. Controlled burning of refuse in landfills has been attempted in some areas to reduce the refuse volume, and produce charcoal in addition to stabilizing the fill. Certain enzymes or catalysts might be developed to speed up chemical or bio-oxidation, and to prevent the formation of corrosive soils.

On the other hand, studies may indicate that satisfactory stabilization could be achieved without complete decomposition. Special grouting techniques, or the use of asphalt or plastic foams or membranes, sulfite liquor, etc., might arrest the decomposition process enough to make it a matter of little concern.

Introduction of air under adequately controlled procedures in order to achieve aerobic decomposition deserves careful investigation.

Just how great a health and safety hazard are the gases that may or do escape from sanitary landfills, is a subject that should likewise receive further consideration.

Research is also needed to develop a method of field testing to measure the degree of soil compaction necessary to prevent the emergence of flies from sanitary landfills. Specifically, the study should correlate instrumentation to the emergence of adult flies from compacted soil.

RESEARCH PROJECT E-2

Title: Effect of sanitary landfill operations on water quality.

Purpose: To determine effective methods for preventing the contamination of pollution of ground waters caused by the migration of microbes and chemicals from landfills into ground and surface waters and estimate degree of danger to public health.

Explanation: It has been shown by Merz and others that ground waters are affected by the presence of refuse in nearby fills.* It has been suggested that asphaltic or plastic membranes might be used to seal off fill sites from the surrounding ground. Other suggestions have been to install impermeable layers of clay beneath the refuse. Sand filter beds might also be effective in areas where the fill does not intercept the water table. Effective methods for controlling the contamination of ground and surface waters would not only protect domestic, recreational, and industrial water supplies, but would clear the way for reclaiming large tracts of land that cannot be used now for sanitary landfill operations. Dangers of contamination from mixed refuse or from rubbish only to ground waters may vary considerably through different types of soils. Further leaching studies are therefore needed to establish adequate safeguards for ground water supplies.

* California State Water Pollution Control Board; Report on the Investigation of Leaching of a Sanitary Landfill, Sacramento, California, 1960.

RESEARCH PROJECT E-3

Title: Development of effective methods of increasing the capacity of sanitary landfills.

Purpose: To prolong the life of a sanitary landfill by achieving greater compaction and volume reduction.

Explanation: Recent studies by Merz and Stone in California reveal that refuse density can be increased by as much as 50% over the normal compacted density, simply by saturating the refuse with water.* Additional volume reductions might be achieved by shredding or compressing refuse and by developing special compaction equipment. High pressure baling of refuse into tightly compressed bundles would reduce volumes and greatly simplify handling operations. Enveloping the compressed bales with air-tight semi-permanent sealants including steel bands, would reduce the hazards of odors, insects, and rodents. Precompressed bales deposited in a masonry-like pattern would utilize available disposal sites to the maximum, would prevent future uneven settlements, and would permit early construction thereon. Research is needed to develop suitable sealants and to modify existing baling machines for this purpose. The pumping of moist air through specially designed underdrains and into the refuse might also increase the fill capacity by accelerating the decomposition of putrescible substances.

*Merz, Robert C., and Ralph Stone, "Scientific Analysis of Sanitary Landfills", American Public Works Association Yearbook, 1961, p.250.

Preliminary experiments on the burning of refuse underground were begun in California several years ago, but were not carried to completion. It was thought that earth cover might be used to screen out hydrocarbons and other products of combustion. Investigations of this type could be extremely beneficial and should be continued, if possible.

More refuse could be placed in a fill if the required amount of cover material could be reduced. This might be accomplished by increasing the lift heights and by decreasing the thickness of the earth cover. The use of spray foams, sealants, and insecticides might be developed that would permit the use of a thinner layer of daily cover material, however, special care should be exercised to prevent the emergence of flies. (See Research Project E-1)

Research Project E-4

Title: Development of effective methods of preventing surface erosion of completed fills.

Purpose: To prevent surface runoff from eroding the protective earth cover and from washing exposed refuse onto adjacent lands.

Explanation: Landfills located on flood plains or in canyons are frequently subject to scouring from surface waters. Studies are needed to determine the relative effectiveness of dikes and drainage systems, special planting and landscaping techniques, and the use of stabilizing materials such as asphalt, cement, and sulfite liquor in protecting fills. More information is also needed to establish adequate safeguards for the protection of public health under such circumstances.

Research Project E-5

Title: Establishment of standards for the development of sanitary landfill sites for pre-determined uses.

Purpose: To develop guidelines for the selection of suitable landfill sites and provide for the efficient development and utilization of such sites.

Explanation: Lack of adequate planning is one reason why satisfactory refuse disposal sites are difficult, if not impossible to find in many areas. By acquiring sites on a long range basis in specific areas, particularly wastelands, and taking into account hauling routes and distances, much more efficient refuse disposal systems can be provided for growing communities at a much lower cost to the taxpayer. Sanitary landfills can be used to reshape the topography into a series of hills and depressions, thus creating more desirable property for the development of parks, golf courses, or even subdivisions. However, there is insufficient information available to draw up fill specifications, which take into account health and sanitation requirements as well as the planned use of the completed fill. Also lacking are official rules within existing building codes which would, under certain specified conditions, allow the construction of structures on previously completed sanitary fills.

Extensive field tests and studies on various types and ages of landfills are needed to obtain necessary design data for incorporation into building codes. Such data would aid in overcoming prejudices against building on stabilized landfills and would permit such construction if precautions against differential settlements, methane gas emissions, odors, and similar hazards were taken into account in designing structures for such locations.

RESEARCH PROJECT E-6

Title: Development of automatic controls and monitoring instruments for operating all components of municipal refuse incinerators more efficiently.

Purpose: To devise methods for accurately measuring incinerator efficiency, and to improve plant operation by maintaining optimal conditions for all components.

Explanation: Because refuse varies so widely in content, skilled operators are required to keep the incinerator operating efficiently with sudden changes in heat value and moisture content. Automatic regulators and control devices would help reduce operating costs and would help to eliminate overloading, overheating, and air pollution. The few instruments currently in use are, in most cases, expensive, unreliable, difficult to repair, and often were not specifically designed for use in refuse incinerators. Research is needed to develop and improve automatic weighing and analyzing equipment, and controls for monitoring stack emissions and regulating feeding rates, temperatures, air flows and auxiliary burners.

Research work now underway at the Taft Sanitary Engineering Research Center and at the Armour Research Foundation clearly demonstrate the feasibility of developing automatic controls and monitoring instruments for municipal incinerators. Such devices might also be used to provide a composite rating of incinerator efficiency by measuring residue as a percentage of wastes handled, weight of stack emissions, content of residue, etc.

RESEARCH PROJECT E-7

Title: Improvement of the existing components of refuse incinerators to reduce overall costs and reduce stack emissions.

Purpose: To improve incinerator design and increase operating efficiency.

Explanation: The basic design of incinerator components - stokers, grates, combustion chambers, refractories, monitoring equipment, etc. - are in need of basic research and development. It has been suggested that an elaborate full-scale study of refuse incinerators, taking into account the effects of wide variations in refuse content and quantities, would be extremely useful to designers and operators alike. The research conducted at the Robert A. Taft Sanitary Engineering Center on incinerators has yielded some good results, but additional work of this type would be very beneficial. Improved linings for combustion chambers are also needed to withstand frequent temperature variations, corrosion, and abrasion. Screens, baffles, fans, ducts, and other parts, are likewise subject to rapid corrosion.

Tall stacks are costly, ugly, detrimental to adjoining properties, hazardous to aircraft, and would not be necessary if improved methods could be developed for inducing draft and for recovering some of the air pollutants emitted from incinerators. Further research in this field may even develop chemical and/or biological systems (filter media, for example,) that could aid in controlling the emission of gases from incinerator stacks.

RESEARCH PROJECT E-8

Title: Development of techniques and devices for economically separating non-combustible and combustible refuse at central incineration plants.

Purpose: To develop methods of separation that would obtain the optimum heat value of refuse, and keep non-combustibles from interfering with normal incinerator operation.

Explanation: A few practical mechanical devices are available for separating materials of various densities, but hand sorting is still the most commonly used method for separating the widely varied components of municipal refuse. Magnets and blowers have been used to extract ferrous metals and papers, but no automatic device is available that will effectively separate organics from inorganics. Such a device would not only reduce the total quantity of refuse normally fed into the incinerator, but would improve the fuel quality, and aid in the recovery of salvageable items. Research might also be undertaken to determine if health considerations warrant the sterilization of non-combustibles; and if so, the methods by which this could best be accomplished.

RESEARCH PROJECT E-9

Title: Complete study of the potential market value and relative merits of refuse compost.

Purpose: To explore the economic feasibility of composting as a refuse disposal method in the United States.

Explanation: Composting has been used successfully for disposing of municipal refuse and other solid wastes in Europe, Asia, and in other places. Although a number of experimental installations have been started in this country, realistic cost accounting information is not available, so that it is impossible to determine whether composting can compete economically with other disposal methods in a given community.

Although some market studies have been undertaken, a major research effort should be made to determine the true value of marketable compost for agricultural and for other purposes. The nutrient value, for example, of composted material should be determined and compared to that of fertilizers and similar products.

The capital and operating costs for producing compost are already known. Even though the market value of compost in some localities may be very small or even zero, the process may still be useful in many instances simply as a means for reducing the volume of refuse, and for rendering it stable.

RESEARCH PROJECT E-10

Title: Development of methods of accelerating the composting process, and of improving the usefulness and quality of the end-product.

Purpose: To reduce the cost of composting by increasing production efficiency, and by increasing the market value of the end-product.

Explanation: It has been suggested that increasing the velocity of oxidation of solid wastes from one-half to two-thirds between composting and incineration would yield ideal results.

Although much work has been done in the field, the use of sewage sludges, animal manures, cannery wastes, and other troublesome putrescible solid wastes should be examined as a means of enriching compost, producing an improved carrier for fertilizers and insecticides, and producing a good cover material for sanitary landfill.

The minimum requirements for bulk storage of compost should likewise be investigated.

RESEARCH PROJECT E-11

Title: Development of package refuse disposal units - grinders, incinerators, shredders, and balers - for use in small communities or at neighborhood transfer stations.

Purpose: To provide small communities with simple, inexpensive methods of refuse disposal, and to reduce the quantities that must be hauled to distant sites in large communities.

Explanation: It was suggested that neighborhood-sized processing and disposal units might be cheaper and more effective than individual on-site disposal units, since they would probably be easier to operate and less costly to maintain. The reduction in haul costs might largely offset the lower capital and operating costs of one or two large central units serving the entire community.

Substations of this type, like substations for other utilities, might be located underground, or housed in attractive buildings convenient to trunk sewers or to above-ground transportation facilities.

RESEARCH PROJECT E-12

Title: Development of improved methods of handling demolition refuse and other bulky wastes.

Purpose: To determine the most economical and satisfactory methods of disposing of bulky wastes and to eliminate the need for open burning of such wastes.

Explanation: Large-scale demolition projects, particularly those undertaken in connection with urban renewal and freeway construction, produce large volumes of waste, much of which is burned on the site. Studies should be made to determine the contribution to air pollution of open burning of such debris. Since bulky wastes are difficult to handle, the feasibility of developing a mobile grinder-incinerator for reducing the wastes as fast as they are produced should be investigated. Measurements, likewise, should be made of the weight and volume of demolition wastes produced per square foot of floor space of buildings being razed to establish guidelines for properly allocating the cost of disposing of such wastes.

RESEARCH PROJECT E-13

Title: Investigation of wet incineration, accelerated chemical and biological decomposition, and other possible methods of refuse reduction.

Purpose: To explore the feasibility of developing more efficient reduction and disposal methods.

Explanation: Pilot studies have indicated that wet incineration may have certain advantages over conventional methods for incinerating sewage sludge. Ground refuse might also be reduced in a similar manner, and used as a carrier for fertilizers and other chemicals, or simply as fill material.

One process now being studied employs fluidized beds for incineration, eliminating the need for high pressures and producing an ash that is practically free of volatiles.

Preliminary studies conducted in California on the distillation of rubbish have resulted in the production of activated charcoal. Additional experiments may yield other useful by-products.

More progress is being made today in the fields of chemistry and physics than was ever imagined possible. These fields should be explored as to methods that lend themselves to refuse reduction and/or disintegration.

APPENDIX A

PARTICIPANTS AT APWA-SPONSORED MEETINGS ON SOLID WASTES RESEARCH NEEDS

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(1) Washington, D.C., January 10, 1962
(2) New York, N.Y., January 11, 1962
(3) Chicago, Ill., February 14, 1962
(4) Los Angeles, Calif., February 23, 1962

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APPENDIX B

NAMES OF RESEARCH INVESTIGATORS AND CONSULTANTS

Listed below are the names of researchers and consultants, who in response to inquiries from the American Public Works Association, have indicated that they would be interested in participating in solid waste research studies. The name, title, and address of each person is given, together with his interest in a particular phase of solid waste research, whenever it was indicated in his response. Additional information concerning the qualifications and experience of those listed is on file at APWA headquarters.

RICHARD W. BOUBEL (MSME), Dept. of Sanitary Engineering, School of Public Health, University of North Carolina, Chapel Hill, N. C., combustion, air hygiene, industrial hygiene.

JOHN W. CLARK (MSCE), Professor and Head, Dept. of Civil Engineering, New Mexico State University, University Park, N. M.; utilization of solid industrial wastes, on-site reduction, composting.

ARTHUR T. COREY (PhD), Dept. of Agricultural Engineering, Colorado State University, Fort Collins, Colo.; movement of solid particles through soils by flowing water.

RICHARD G. COULTER (MCE), Associate Professor, Dept. of Civil Engineering, The City College, Convent Avenue at 139th Street, New York 17, N.Y.; community facilities planning.

GORDON M. FAIR, Professor of Sanitary Engineering, Harvard University, Cambridge 38, Massachusetts; water carriage of solid wastes.

F. FREEMAN FUNK (MSCE), City Manager, City of Fredericksburg, Box 239, Fredericksburg, Va.; collection systems, waste production controls.

TOMMY GINGLES (MSCE), Associate Professor, Dept. of Civil Engineering, University of Mississippi, University, Miss.; water carriage of solid wastes.

WERNER N. GRUNE (ScD), Professor of Sanitary Engineering, Dept. of Civil Engineering, Georgia Institute of Technology, 225 North Avenue, N.W., Atlanta 13, Ga.; garbage composting for recovery of industrial alcohols, anaerobic digestion of garbage.

S. A. HART (PhD), Associate Professor of Agricultural Engineering, University of California, Davis, California; technical and economic study of refuse disposal by combining municipal refuse with agricultural, cannery, demolition, animal, and other solid wastes.

H. HEUKELEKIAN (PhD), Chairman, Dept. of Sanitation, Rutgers University, New Brunswick, N. J.; microbiology and biochemistry, composting.

WILLIAM T. INGRAM (MPH), Adjunct Professor, Dept. of Civil Engineering, New York University, University Heights, New York 53, N. Y.; incinerator residues, air cleaning and monitoring devices for control of stack emissions, landfill cover materials, theory of aerobic and anaerobic decomposition of refuse; collection routing, techniques, and methodology.

SUSUMU KARAKI (MS), Dept. of Civil Engineering, Colorado State University, Fort Collins, Colo.; transport of solid wastes through pipelines.

HARVEY F. LUDWIG (MSCE), President, Engineering-Science, Inc., 150 East Foothill Blvd., Arcadia, Calif.; refuse collection systems, grinding, composting, ground water contamination from sanitary fills.

JESSE V. LUNSFORD (MSCE), Associate Professor, Dept. of Civil Engineering, New Mexico State University, University Park, N. M.; waste reclamation processes, landfill stabilization.

WALTER R. LYNN (PhD), Associate Professor of Sanitary Engineering, Cornell University, Ithaca, New York; systems of analysis of solid waste collection operations.

P. H. McGAUHEY (MSCE), Director, Sanitary Engineering Research Laboratory, University of California, Berkeley, Calif.; technical and economic study of refuse disposal by combining municipal refuse with agricultural, cannery, demolition, animal, and other solid wastes.

J. E. McKEE (ScD), Professor of Environmental Health Engineering, California Institute of Technology, Pasadena, Calif.; basic solid wastes research.

ROSS E. McKINNEY (ScD), Professor of Civil Engineering, Environmental Health Laboratory, University of Kansas, Lawrence, Kansas; biological decomposition of solid wastes.

ROBERT C. MERZ (MSCE), Professor of Civil Engineering, University of Southern California, Los Angeles 7, Calif.; leaching and gas production in sanitary landfills.

ABRAHAM MICHAELS (BME), Deputy Street Commissioner, Room 924, City Hall Annex, Philadelphia 7, Pa., refuse collection, incineration, landfill, street cleaning.

S. M. MORRISON, (PhD), Professor of Microbiology, Dept. of Pathology & Bacteriology, Colorado State University, Fort Collins, Colorado; conversion of agricultural and industrial wastes to usable products, metabolism of microorganisms in aerobic waste digestion.

R. SAGE MURPHY (MSCE), Research Assistant, Dept. of Civil Engineering, Pennsylvania State University, University Park, Penna.; utilization of industrial solid wastes, incineration of domestic solid wastes.

JOHN B. NESBITT, (ScD), Associate Professor, Dept. of Civil Engineering, Pennsylvania State University, 216 Sackett Bldg., University Park, Penna., economics of composting, methane gas production in sanitary landfills.

BERNARD NEWMAN (PhD), Director, Newing Laboratories, Inc., 260 Islip Ave., Islip, N. Y.; gas production in sanitary landfills, mesophilic and thermophilic biochemical reactions, influence of chemical additives for decreasing the permeability of landfill cover material.

DANIEL A. OKUN, (ScD), Head, Dept. of Sanitary Engineering, P. O. Box 899, University of North Carolina, Chapel Hill, N. C.; air pollution, incineration.

SAMUEL P. OWEN (MA), Professor of General Engineering, Rutgers University, New Brunswick, N. J.; refuse collection systems, regional refuse disposal systems.

FREDERICK G. POHLAND (PhD), Assistant Professor of Sanitary Engineering, Georgia Institute of Technology, Atlanta 13, Georgia; composting, utilization of industrial solid wastes.

LYMAN A. RIPPERTON (PhD), Assistant Professor of Sanitary Science, School of Public Health, University of North Carolina, Chapel Hill, N. C.; air pollution from incinerators.

CASIMIR A. ROGUS, (MSCE), Director of Engineering, Dept. of Sanitation, The City of New York, 125 Worth Street, New York 13, N. Y.; refuse collection systems, incineration, sanitary landfills, composting.

CARL SCHNEIDER (MSME), Consulting Engineer, 202 Pan-American Building, New Orleans 12, La.; utilization of incinerator residue and other solid wastes, sanitary landfills.

DR. KARL L. SCHULZE (PhD), Associate Professor, Civil Engineering, Michigan State University, E. Lansing, Michigan; thermophilic composting of combustible refuse and sewage sludge.

HILLEL I. SHUVAL, Visiting Associate Professor, Dept. of Environmental Health, School of Public Health, University of Michigan, Ann Arbor, Michigan; composting.

DARYL B. SIMONS (PhD), Professor of Civil Engineering, Colorado State University, Fort Collins, Colorado; transportation of solids in pipes and in open channels.

JOHN R. SNELL (ScD), President, John R. Snell Engineers, Inc., 221 North Cedar St., Lansing 29, Michigan; methods and economics of municipal composting, household grinding of refuse and central grinding of municipal refuse.

RALPH STONE (MSCE), President, Ralph Stone & Company, Inc., Engineers, 10960 Santa Monica Boulevard, Los Angeles 25, Calif.; reclamation, collection, landfill, incineration, composting.

JEAN L. VINCENZ (MPA), Director of Public Works, San Diego County, 4005 Rosecrans, Bldg. 8, San Diego 10, Calif.; operation, financing, and regulation of refuse collection and disposal systems, salvaging, sanitary landfill.

HARVEY WILKE (MSCE), Professor of Sanitary Engineering, Purdue University, Lafayette, Indiana; effects of sanitary landfill on ground water quality.

APPENDIX C

DETAILED SAMPLE RESEARCH PROJECT

Title: Analysis of Solid Waste Collection Systems

Specific Aims: As is the case with many industries, refuse collection and disposal has largely developed and expanded through the individual efforts of independent organizations. Advancements in this field have come about mainly through the efforts of individuals attempting to solve particular problems in special situations and communicating their attempts and results to other persons having similar problems. However, these solutions presented to meet "immediate" situations have too frequenly resulted in obscuring analysis of the total problem of refuse collection. It is obvious that satisfactory solutions to this problem cannot be obtained by viewing each operation within the processes of refuse collection as an independent unrelated function. Rather,in order to achieve efficient solutions to these problems effort must be directed toward viewing the problem in its entirety as an interconnected system of component operations and functions.

Unfortunately, until comparatively recently, solutions to this class problem have been unavailable because of the difficulty in making a systematic analysis of large complex problems. However, the advent of new mathematical techniques in systems analysis and operations research coupled with the availability and facility of high speed computing devices will now permit investigations of this type.

The purposes of this study are to construct a model of the refuse collection problem containing detailed descriptions of its critical components and to develop analytical techniques which will permit determination of optimal solutions to the problems associated therewith. It is intended that the models which will be developed will be sufficiently general that they may be utilized for planning, design and analytical purposes.

Method of Procedure:

At the outset it is proposed to develop optimal solutions to separate facets of the total problem which will have immediate application and utility. Finally these separate solutions will be coupled in order to view the refuse collection problem in its entirety.

1. Determination of Optimal Paths for Vehicles Collecting Solid Wastes.
   a) In view of the fact that collection of refuse by current practices amounts to more than 75% of the costs for the total operation, considerable effort will be directed toward this problem. Initially it will be assumed that a community has existing collection sites, garage factilities, numbers of vehicles, transfer stations, and disposal sites which are rigidly fixed and that it is necessary to determine the paths to be followed by each vehicle in order to optimize a desired criterion function (e.g., minimize cost, minimize travel time.) This highly constrained model can then be analyzed for anticipated community growth.

   b) Extensions from the basic model can be made in terms of optimizing the following characteristics of the system by relaxing constraints previously imposed or adding constraints to be able to assess the effects of: 1) location of garaging facilities; 2) location of disposal sites; 3) frequency of collection; 4) location of transfer sites; 5) number of vehicles; 6) vehicle capacities; 7) varying the number of men per collection crew; 8) separate collection of two or more classes of refuse; 9) location of storage sites.

c) Extensions from the basic model can be made in terms of optimizing the following characteristics of the system by relaxing constraints previously imposed or adding constraints to be able to assess the effects of: 1) location of garaging facilities; 2) location of disposal sites; 3) frequency of collection; 4) location of transfer sites; 5) number of vehicles; 6) vehicle capacities; 7) varying the number of men per collection crew; 8) separate collection of two or more classes of refuse; 9) location of storage sites.

2. Determination of Optimum Size of Collection Vehicle Containers (Capacity).

An analysis of the economics of vehicle loads will be made independent of the availability of existing types of equipment in order to determine optimal capacity. This determination will be constrained by considerations of labor policies, traffic flow, street loads, etc. The analysis should provide insight into the general load problem which would impart direction to the development of more efficient proprietary equipment. Additional analysis can be made to determine the most effective capacity among the types currently available.

3. Determination of Optimum Size, Shape and Material for Household Containers

This problem can be stated in terms of the weight, volume and storage characteristics (shape) from the viewpoints of the householder and the collector. Consideration will be given to differences in conditions surrounding multiple and single-family dwelling units.

4. Cost Analysis of Refuse Collection and Disposal.

An essential aspect of this research is dependent upon collection of meaningful data as to current practices and costs of solid refuse collection and disposal. It will be necessary to collect and collate cost information in order to make assessments of the model. However, the collection of data will be delayed until the models described above have been developed in order that the collected cost information can be of maximum utility. In many cases the models will dictate the type and form of information which is needed. A considerable quantity of potentially useful data are available and the cooperation of agencies having much information will be solicited in order to avoid unnecessary duplication of effort. In addition to cooperation in supplying data it will be necessary to consult experienced persons in the field of solid refuse collection and disposal. The assistance of such persons is considered to be essential to the successful completion of the proposed project. The following persons have indicated their willingness to participate in this research as consultants: Abraham Michaels, Deputy Street Commissioner, Philadelphia, Pa.; Casimir A. Rogus, Director of Engineering, Department of Sanitation, New York City; Arthur T. Brokaw, Engineer and Director, Department of Engineering, Princeton, New Jersey; William S. Foster, Editor, American City Magazine; William A. Xanten, Supt., Division of Sanitation, Washington, D.C.

Significance of the Research: The ability to understand and evaluate the complex interrelated operations involved in refuse collection and disposal as a complete system will be of considerable value to improving an aspect of environmental control. In problems of design, planning and operation the primary concern is no longer restricted to developing methods of executing a particular task, but rather how to

choose from among a set of existing methods. Present technology will permit us to "solve" refuse problems in a variety of ways and (although research is needed in order to enlarge and improve methodology) it is also necessary to provide techniques for choosing among such alternatives as may exist. As urban areas increase in area and population the problems of providing urban services such as refuse collection and disposal will rise but at a higher rate. The need to find efficient solutions to these problems, while already urgent, will become more and more critical.

As stated earlier, it is intended that this research shall finally provide a useful tool to the field of environmental engineering in that the solutions sought shall be in terms of general cases which can be readily adapted for use in any community.

Research Facilities: Cornell has a modern center for high-speed electronic computing with which the department is closely associated and which it utilizes heavily in its teaching and research program. The Center at present has a Burroughs 220 computer with excellent related facilities. A CDC 1604 Computer was purchased recently as a major addition to the Center's facilities. Several analog computers and other computing equipment are located elsewhere on the campus.

Library facilities relevant to the proposed research are excellent. The Engineering Library in Carpenter Hall was built in 1957 and includes some 50,000 volumes. The large holdings in Sanitary Engineering and Industrial Engineering are supplemented by a sizeable collection in the mathematics library. The Olin Research Library together with nine college and school libraries compose a collection of more than 2,000,000 volumes.

Considerable lateral support is available to this project from departments (such as City and Regional Planning, Economics and Mathematics) having an interest in these types of problems.

Previous Work done on this Project and Results obtained by others: Idealizations and gross simplifications of this problem have existed in the research literature of operational analysis for at least a decade. The only model which has been adequately detailed and treated is the so-called Traveling-Salesman problem. This is the hypothetical problem of a salesman who desires to tour each of n cities in the minimal amount of time or distance traversed. The analogue in the collection of solid wastes is the case of one collection vehicle which must service the entire community. The methods for dealing with this problem are sparse. The first comprehensive discussion of the problem is by Flood, "The Traveling-Salesman Problem" in Operations Research, (Feb. 1956). He does not proffer a solution but does summarize the failures of mathematicians to that time. A solution, albeit not too efficient, appeared in 1958 by Croes, "A Method for Solving Traveling-Salesman Problems" Operations Research, (Nov. 1958).

The case of more than one collection vehicle, the more common situation, has never been mentioned in the literature. It appears that this type of problem is a particularly important generalization of the Traveling-Salesman problem and has ramifications in a multitude of situations: for example, in the scheduling of school busses, and in the processing of jobs by a department of identical machines, in addition to the collection of solid refuse by a number of vehicles.

It appears that optimal solutions are not feasible-infeasible due to both the fact that alogarithms do not exist, or if they did, they would be too time consuming even with the speediest of electronic computers. The interest then turns to suboptimal or good approximate solutions, as has occurred in many other similar cases in which a practical formulation of the problem is very difficult mathematically.

The Traveling-Salesman problem is in fact a very special case of a general class of problems known as quadratic assignment problems. Among the applications of the quadratic assignment problem is the case of the assignment of production facilities to possible locations in an industrial complex in order to minimize the product of the distance moved and the weight of material moved.

A considerable amount of information related to quantity, quality, of solid refuse exists in the literature and in comprehensive engineering reports. Studies of collection times, service level, containerization, work pace, vehicle types and other pertinent issues have been ably reported in "An Analysis of Refuse Collection and Sanitary Landfill Disposal" by the American Public Works Association, (1958). A great deal of the information contained in these publications will be extremely valuable to this study and additional data collection will be approached as supplementing this material.

Carrabine, J.D., "Determination of Optimum Sizes and Economics Feasibility of Shipping Containers Using O. R. Techniques", Jo. of Ind. Engr. v.9,n,6, p. 513.

Personal Publications

Lynn, W.R. and A. Charnes, "The Dyadic Computation of a Generalized Network Model of a Sewage Treatment System", O.N.R. Res. Memo. #19, Northwestern University, October, 1959.

Lynn, W.R. and J.A. Logan, and A. Charnes, "The Use of Systems Analysis in Planning Sewage Treatment Works", Jo.W.P.C.F., (In Press).

Logan, J. A. Hatfield, W.D., Russell, G.S., and Lynn, W.R., "An Analysis of the Economics of Sewage Treatment", W.P.C.F. (In Press).

Maxwell, W.L., "A Note on the Assignment of Facility Location", Journal of Ind. Engr. (January 1961).

Justification of Budget

1. Personnel - Principal research responsibility will be carried by a professional staff who will participate one-half time during the academic year and full time during the summer. The research assistants will be designated Graduate students in sanitary engineering and industrial engineering and will contribute approximately 20 hours per week toward this project during the academic year and full time during the summer. The principal investigator's salary will not be charged to this project in view of his existing support under PHT-1-77a. The subject of this proposal falls within the broad subject implications of the training grant (PHT-1-77a), consequently it was deemed reasonable to assign 10% of his time to this project without reallocation of funds.
2. Permanent Equipment - None required.
3. Consumable Supplies - Primary expenditure will be for computer time. The Cornell Computer Center is equipped with a Burroughs 220 (and as of August 1962 will have a CDC 1604) which are available for research investigations. The charge for machine time on the 220 is at the rate of $125.00 per hour, which permits a time allocation for this project of 16 hours. The computing center has offered to match our research funds appropriations for computer time thus permitting a total machine time of 32 hours.

4. Travel - This figure represents the travel cost involved in meetings with project consultants (generally to be held in New York City). Travel costs will be incurred by consultants and professional staff. Some small amount of travel funds may be used by staff in summers for data collection investigations.

5. Other Expense - The following persons (suggested by the American Public Works Association as experts in the field of solid wastes collection) have indicated that they would be willing to act as consultants to this research project:

Abraham Michaels
Deputy Street Commissioner
City Hall Annex, Rm. 924,
Philadelphia, Pa.

Casimir A. Rogus
Director of Engineering
Dept. of Sanitation
125 Worth Street
New York, New York

Arthur T. Brokaw
Engineer and Director
Department of Engineering
Borough Hall
Princeton, New Jersey

William S.Foster, Editor
American City Magazine
470 Park Avenue, South
New York 16, New York

William A. Xanten
Supt. of Division of Sanitation
District Building, Rm. 3,
Washington 1, D.C.

These funds will be utilized for consulting fees during periods when such consultations are required.

APPENDIX D

SELECTED REFERENCES

APWA Committee on Refuse Collection, Refuse Collection Practice, 2nd edition, Public Administration Service, 1958.

APWA Committee on Refuse Disposal, Municipal Refuse Disposal, Public Administration Service, 1961.

International City Managers' Association, Municipal Public Works Administration. 5th edition, 1957.

McKee, Jack E., et al, 100 Problems in Environmental Health, U.S. Public Health Service, Washington, D.C., 1961.

Proceedings of the ad hoc Study Group on Community Solid Waste Disposal, U.S. Public Health Service, Washington, D.C., March 14-15, 1957.

Proceedings, Seventh International Public Cleansing Congress, Goteborg, Sweden, 1961.

Report of the Committee on Environmental Health Problems, Paul M. Gross, Chairman, Public Health Service Publication No. 908, U.S. Government Printing Office, Washington, D.C., 1962.

American City Magazine, Buttenheim Publishing Corp., 470 Fourth Avenue, New York 16, New York

Public Cleansing, Institute of Public Cleansing, 28 Portland Place, London W.1.

Public Works, Public Works Journal Corp., 200 South Broad Street, Ridgewood, New Jersey

Refuse Removal Journal, RRJ Publishing Corp., 60 East 42nd Street, New York 17, New York

Compost Science, Rodale Press, Inc., 33 East Minor Street, Emmaus, Pa.

U.S. Public Health Service Annotated Bibliography Series:

Refuse Collection and Disposal

Composting of Organic Wastes